TITLE OF THE INVENTION

OPTICAL TRANSMISSION APPARATUS AND METHOD WHICH ADJUST RISE AND FALL TIME OF SIGNAL LIGHT TO BE TRANSMITTED

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on, and claims priority to, Japanese application number 10-071525, filed on March 20, 1998, in Japan, and which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an optical transmission apparatus and method for restraining influence of wavelength dispersion characteristics or nonlinear effect of a transmission path. More specifically, the present invention relates to an optical transmission apparatus and method which adjusts rise time and/or fall time of signal light to be transmitted, to thereby reduce waveform deterioration of the signal light after transmission.

2. Description of the Related Art

Optical communication systems using fiber optical transmission lines are being used to transmit relatively large amounts of information. However, as users require larger amounts of information to be rapidly transmitted, and as more users are connected to the systems, a further increase in the transmission capacity of optical communication systems is required.

Therefore, there is a continual effort in increase transmission capacity of optical communication systems. In the electrical field of art, Time-Division Multiplexing (TDM) is being used to increase transmission capacity. In the optical field of art, Optical Time-Division Multiplexing (OTDM) and Wavelength-Division Multiplexing (WDM) are being used to increase transmission capacity. Further, optical fiber amplifiers, such as erbium doped

fiber amplifiers (EDFA), are being used to realize very long distance optical transmission.

With high-speed transmission in a very long distance optical communication system of large-capacity which utilizes WDM and optical amplifiers, the waveform of the transmitted signal is distorted. This distortion is due, for example, to interaction of spectral spread of signal lights caused by modulation, and to phase chirping caused by a nonlinear effect of an optical fiber, with the wavelength dispersion characteristics of the transmission path. Distortion results in deterioration of transmission characteristics, thereby restricting the transmission rate and the transmission distance.

Therefore, in very long distance optical communications systems having large-capacity, it is important to restrain the wavelength dispersion characteristics of the transmission path.

A conventional technique for restraining influence of wavelength dispersion is disclosed in Japanese Unexamined Patent Publication Nos. 2-30233, 8-237222, 9-116493, and 5-183511, which are incorporated herein by reference. These Japanese Unexamined Patent Publications disclose several techniques, such as (a) a method for offsetting wavelength dispersion characteristics of a transmission path by providing a dispersion compensator which generates dispersion having a sign opposite to the dispersion in the transmission path, (b) a method in which a signal light is provided with pre-chirping at a transmitter, and (c) a method for restricting an influence of wavelength dispersion by combining the above-mentioned dispersion compensator with pre-chirping. In this respect, the term "pre-chirping" indicates that a baseband signal is, in addition to light intensity modulation therefor, intentionally provided with optical phase modulation or optical frequency modulation to restrain spread of waveform due to wavelength dispersion.

However, in these techniques, the amount of dispersion compensation and/or pre-chirping will vary depending on various parameters such as the type of transmission system, transmission rate, type of transmission path, and distance of transmission path. Thus, such amounts must be respectively optimized for each optical communication system. Amounts such as for dispersion compensation and/or pre-chirping, which are optimized for each optical communication system, are assumed to be fixed at the time of introduction of the system. Consequently, it is difficult to extensively change or fine-tune the amounts.

Additionally, it is difficult to commonly use a transmitter, to which pre-chirping is applied, among different types of optical communication systems, since the amount of pre-chirping is different for different optical communication systems. For example, even if it is attempted to commonly apply a transmitter in an optical communication system having a transmission rate of 10 Gb/s to an optical communication system having a transmission rate of 2.5 Gb/s, it is difficult to realize such an attempt because the optimum amount of pre-chirping would be different for each system.

As should be understood from the above, even for those optical communication systems which have configurations similar to one another, it is necessary to develop optical devices which are matched with each system, thereby increasing the number of parts to be developed, and thereby increasing cost.

Further, in a WDM optical communication system in which a plurality of signal lights having different wavelengths are multiplexed together and then transmitted, there occurs fluctuation of transmission qualities between channels (i.e., between signal lights multiplexed together). Such fluctuation is due, for example, to influence of dispersion slope of a transmission path. To avoid this fluctuation, it is necessary, for example, to adopt a dispersion compensator

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which is capable of compensating the dispersion slope, or to optimize a compensation amount for dispersion and/or an amount of pre-chirping, individually to each of the wavelengths. Unfortunately, such techniques are too expensive since the number of parts is increased if optimization is effected for each of the wavelengths. As a result, the cost of an optical communication system is greatly increased.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an optical transmission apparatus and method for restraining the influence of wavelength dispersion characteristics and nonlinear effect of a transmission path, and which can be flexibly adapted to different optical communication systems.

Objects of the present invention are achieved by providing an optical transmitter transmitting a signal light to a transmission path, wherein the signal light has a corresponding rise time and fall time and the transmitter adjusts the rise time and/or the fall time.

Objects of the present invention are also achieved by providing an apparatus which includes an adjusting circuit and a modulator. The adjusting circuit adjusts a rise time and/or a fall time of an electrical modulation signal. The modulator modulates a light with the adjusted electrical modulation signal. Based on a bit rate of the optical communication system and a desired rise time and/or fall time, the adjusting circuit can (a) shorten the rise time and/or the fall time, or (b) lengthen the rise time and/or the fall time. In other embodiments, the adjusting circuit can adjust the rise time and/or the fall time to maintain amplitude deterioration and phase margin of the modulated light to be within a specific range after being transmitted through a transmission path and received by a receiver .

In addition, objects of the present invention are achieved by providing an

optical communication system which includes a transmitter, a receiver and a controller. The transmitter includes an adjusting circuit adjusting a rise time and/or a fall time of an electrical modulation signal, and a modulator modulating a light with the adjusted electrical modulation signal. The transmitter then transmits the modulated light through a transmission path. The receiver receives the transmitted, modulated light through the transmission path. The controller controls the adjusting circuit to adjust the rise time and/or the fall time in accordance with characteristics of the modulated light at the receiver.

Further, objects of the present invention are achieved by providing a method which includes (a) adjusting a rise time and/or a fall time of a signal light; and (b) transmitting the adjusted signal light through a transmission path. The method can also include (c) receiving the transmitted signal light from the transmission path, wherein said adjusting adjusts the rise time and/or the fall time in accordance with characteristics of the received signal light.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and, in part, will be obvious from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of the invention will become apparent and more readily appreciated from the following description of the preferred embodiments, taken in conjunction with the accompanying drawings of which:

FIG. 1 is a diagram illustrating an optical communication system, according to an embodiment according to the present invention.

FIGS. 2(A) through 2(E) are graphs showing waveforms of signal lights to be transmitted, respectively, in a waveform simulation performed according to an embodiment of the present invention.

FIGS. 3(A) through 3(E) are graphs showing waveforms of received signal lights, respectively, when the power of signal light input to a transmission path is set at 0 dBm, in a waveform simulation performed according to an embodiment of the present invention.

FIGS. 4(A) through 4(E) are graphs showing waveforms of received signal lights, respectively, when the power of signal light input to a transmission path is set at 5 dBm, in a waveform simulation performed according to an embodiment of the present invention.

FIGS. 5(A) through 5(D) are graphs showing variations of amplitude deterioration and phase margin, when the power of input signal light is varied in a waveform simulation performed according to an embodiment of the present invention.

FIGS. 6(A) and 6(B) are graphs showing exemplary waveforms of signal lights to be transmitted, the t_r and t_f of which are optimized, respectively, according to an embodiment of the present invention.

FIG. 7 is a graph showing a waveform of a signal light to be output from a transmitting part which is used in a conventional optical communication system of 10 Gb/s.

FIG. 8 is a diagram illustrating an optical communication system according to an embodiment of the present invention.

FIG. 9 is a diagram illustrating an example of an adjusting circuit, according to an embodiment of the present invention.

FIG. 10 is a diagram illustrating an optical communication system, according to an additional embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred

embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

FIG. 1 is a diagram illustrating an optical communication system, according to an embodiment of the present invention. Referring now to FIG. 1, a transmitting part 1 is an optical transmitting device which generates a signal light with the rise time and fall time thereof being adjusted. Transmitting part 1 sends the adjusted signal light to a transmission path 2. A receiving part 3 is an optical receiving device which receives the signal light transmitted via transmission path 2, and processes the received signal light. Transmission path 2 and receiving part 3 are identical with those adopted in conventional systems, and important aspects of the present invention reside in transmitting part 1.

Transmitting part 1 includes a light source (LD) 11, a modulation signal generator 12, a $t_r t_f$ adjusting circuit 13 and an optical modulator (MOD) 14. Light source 11 is typically a laser diode and generates, for example, a continuous light having a wavelength of λ, for a general optical communication. However, light source 11 is not intended to be limited to such a light source, and various other types of light sources can be used.

Modulation signal generator 12 generates an electrical modulation signal corresponding to a transmission signal. $t_r t_f$ adjusting circuit 13 is a waveform adjusting part which adjusts the rise time (to be referred as t_r hereinbelow) and fall time (to be referred as t_f hereinbelow) of the modulation signal from modulation signal generator 12. Optical modulator 14 modulates the light from light source 11, in accordance with the modulation signal adjusted by $t_r t_f$ adjusting circuit 13.

Modulation signal generator 12 generates a modulation signal which represents data to be transmitted (transmission signal) at a predetermined transmission rate and with a predetermined encoding format.

$t_r t_f$ adjusting circuit 13 transforms the waveform of the modulation signal at its rising and falling portions by, for example, passing the modulation signal from modulation signal generator 12 through, for example, an electric filter having an appropriate band. At this time, it can be assumed that the t_r and t_f of the modulation signal are optimized by varying the band of an electric filter of $t_r t_f$ adjusting circuit 13 in accordance with, for example, reception characteristics of receiving part 3, as described later. The adjusted modulation signal is then sent to optical modulator 14 so that a signal light, the t_r and t_f of which are adjusted, is generated.

To adjust the t_r and t_f of the signal light, it is possible to transform the amplitude of the modulation signal, instead of the aforementioned method in which the waveform of the modulation signal is transformed at its rising and falling portions such as by an electric filter. This substitutional transforming method is provided by making use of such an effect that the t_r and t_f of the signal light to be output are changed as a result of the modulating operation of optical modulator 14 by transforming the amplitude of the modulation signal. In addition, there can be envisaged such a method to adopt an optical filter, or wavelength dispersion apparatus, in the optical field of art.

There are many types of optical modulators which can operate as optical modulator 14. For example, optical modulator 14 can be an optical intensity modulator of MachZehnder interferometer type which utilizes lithium niobate ($LiNbO_3$). By applying the modulation signal output from $t_r t_f$ adjusting circuit 13 to the electrodes of such an optical modulator 14, the refractive index of an optical waveguide path is changed by an electrooptic effect, to thereby modulate the intensity of the light from light source 11, causing generation of a signal light which has t_r and t_f corresponding to the modulation signal. Although not shown in FIG. 1, as with the technique described in the Background of the Invention section, the signal light can be applied with pre-chirping by

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modulating the optical phase or optical frequency of the signal light, at optical modulator 14. Thus, optical modulator 14 can also have a function as a modulation part of the signal light.

Transmission path 2 can have many different configurations. For example, in FIG. 1, transmission path 2 includes alternately connected single mode optical fibers (SMF) 21 and optical amplifiers 22, where fibers 21 exhibits zero-dispersion near a wavelength of 1.3 μm. It is assumed herein that the whole length (transmission distance) of transmission path 2 is L, the number of repeater sections (i.e., number of SMFs) is N, and the distance of repeater section (i.e., length of each SMF) is "1". As the transmission path, there may be adopted, for example, a dispersion shift fiber (DSF) or dispersion compensation fiber (DCF), instead of, or in addition to, SMF 21.

The light emitted from light source 11 of transmitting part 1 is sent to optical modulator 14. Moreover, optical modulator 14 receives the modulation signal having its rising and falling portions shaped by $t_r t_f$ adjusting circuit 13. Thus, the light from light source 11 is, for example, intensity modulated in accordance with the modulation signal, and is applied, for example, with pre-chirping. The signal light output from optical modulator 14 is then transmitted to receiving part 3, by passing through SMFs 21 and optical amplifiers 22 of transmission path 2. Since the signal light is transmitted via transmission path 2, it is influenced by, for example, wavelength dispersion characteristics and/or nonlinear effect of each of SMF 21.

Nonetheless, in the present embodiment of the present invention, the signal light to be transmitted from transmitting part 1 to receiving part 3 has, for example, been applied with pre-chirping, and the t_r and t_f of the signal light have been optimized. Thus, even when the signal light is influenced by, for example, the wavelength dispersion characteristics of transmission path 2, the influence is offset such that the deterioration degree of waveform is restrained.

The signal light having a reduced waveform deterioration is then received at receiving part 3, resulting in improvement in reception sensitivity of receiving part 3.

There will be explained hereinafter the improving effect for the waveform deterioration by the optimization of t_r and t_f of signal light to be transmitted, based on the following results of waveform simulation. In the simulation model adopted herein, there is assumed a transmission of one cycle of wavelength of signal light, such as having a transmission rate of 2.5 Gb/s, and a transmission distance L of 640 km (i.e., the number N of repeater sections = 8, and the distance "l" of repeater section = 80 km). Further, the calculation assumes that α parameter indicative of a value of pre-chirping is +1, a dispersion value of each SMFs 21 is +16.7 ps/nm/km, and no dispersion compensators are used.

FIGS. 2(A) through 2(E) show examples of waveform (eye-pattern) of the signal light which is output from transmitting part 1, when the t_r and t_f are changed.

In FIGS. 2(A) through 2(E), each of the waveforms show an eye pattern of the signal lights under the condition that the t_r and t_f are quickened in the order of from "a" to "e" ($a > b > c > d > e$). As seen from these figures, the quicker the t_r and t_f are, the steeper the rising and falling of the signal light are. A waveform of signal light which has been adopted in the conventional 2.5 Gb/s transmission is closely similar to that shown in FIG. 2(B).

FIGS. 3 and 4 show the waveforms (eye patterns) of the received signal light, when each of the signal lights shown in FIGS. 2(A) through 2(E) has been transmitted up to receiving part 3 via transmission path 2. FIGS. 3(A) through 3(E) show waveforms, respectively, when a power Pin of signal light input to SMF 21 of each of the repeater sections is set at 0 dBm, while FIGS. 4(A) through (E) show waveforms, respectively, when the power Pin of input signal

light is set at +5 dBm.

In these figures, the deterioration of pulse waveform due to wavelength dispersion characteristics of the transmission path is expressed by the fact that the opening part of eye pattern is narrowed (decrease of the eye opening degree) due to pulse compression or pulse broadening. In order to restrain the pulse waveform deterioration, it is enough to previously set the t_r and t_f of the pulse waveform of the signal light to be transmitted, in a direction opposite to the deteriorating direction. Namely, the t_r and t_f shall be set in a delayed manner, in case that the waveform deterioration is to be caused by pulse compression, and the t_r and t_f shall be set in a quickened manner, in case that the waveform deterioration is to be caused by pulse broadening.

In case that α parameter has a positive value here, there is caused pulse broadening when the signal light is transmitted through a transmission path having positive dispersion. Thus, by quickening the t_r and t_f to thereby restraining the pulse broadening, the waveform deterioration be reduced.

Meanwhile, in case of generation of Self Phase Modulation (SPM), which is a nonlinear effect of the transmission path, as a result that the power Pin of signal light input to each of optical fibers 21 is increased, there will occur pulse compression in a transmission path having positive dispersion. Thus, an effect obtained when the power Pin of input signal light is large functions in a manner opposite to that obtained when the power Pin is small with respect to the transmission pulse. Comparing each of the waveforms of FIGS. 3(A) through 3(E) with those of FIGS. 4(A) through 4(E), it is seen that those waveforms of FIGS. 4(A) through 4(E), in which the power Pin of input signal light is increased, are more compressed with respect to pulse thereof, due to the effect of SPM, so that the t_r and t_f are quickened.

As described above, the waveform deterioration of the received signal can be reduced, by adjusting the t_r and t_f of the signal light, at transmitting part

1. The values of t_r and t_f should be set in consideration of their relationship to the reception characteristics of receiving part 3, and to the power of signal light to be input to the transmission path.

Shown in FIGS. 5(A) through 5(D) are variations of amplitude deterioration and phase margin, where the t_r and t_f are set from "b" to "e", and the power Pin of signal light input to the transmission path is varied. In these figures, the amplitude deterioration is represented by a circular mark (left ordinate), and the phase margin is represented by a triangular mark (right ordinate). Here, it can be said that the smaller value of amplitude deterioration is preferred, and so is the larger value of phase margin.

As shown in FIGS. 5(A) through 5(D) (t_r and t_f are "b" to "e", respectively), as the t_r and t_f are quickened, the amplitude deterioration is drastically improved though the phase margin becomes smaller. As noted above, t_r and t_f are required to be set such that the dynamic range is widened as much as possible, taking into consideration of the reception characteristics of receiving part 3. For example, considering such a case that the reception characteristics of receiving part 3 are required to have amplitude deterioration equal to or less than 20 % and phase margin equal to or greater than 60 %, there can be ensured a wider dynamic range when the t_r and t_f are set, for example, at "d" or "e" which are quicker values.

Shown in FIGS. 6(A) and 6(B) are examples of the t_r and t_f of the signal light to be transmitted in a conventional optical communication system of 2.5 Gb/s, in which the aforementioned optimization is effected, as follows.

FIG. 6(A) shows a conventional waveform of the signal light to be transmitted before optimization of t_r and t_f, in which the t_r and t_f of this signal light are in the order of 70 ps. It is confirmed that the values of t_r and t_f designate the rise time and fall time, respectively, within the range from 20% to 80% of the amplitude of signal light. Contrary, FIG. 6(B) shows a waveform

of the signal light to be transmitted after optimization of t_r and t_f, in which the t_r and t_f are set at approximately 30 ps. Excellent transmission characteristics can be obtained when transmission is conducted at 2.5 Gb/s making use of the thus optimized waveform.

5   In the above, the signal light shown in FIG. 6(B), in which t_r and t_f are in the order of approximately 30 ps, can be also obtained simply by employing a transmitting part of a conventional 10 Gb/s optical communication system, as it is, as that for 2.5 Gb/s. In other words, the transmitting part of conventional 10 Gb/s optical communication system is designed to output a signal light, the t_r

10 and t_f of which are in the order of 30 ps, such as shown in FIG. 7 (however, there is not provided any function to adjust the t_r and t_f). Thus, the signal light adapted for 2.5 Gb/s such as shown in FIG. 6(B) can be obtained when the transmitting part for 10 Gb/s is driven by 2.5 Gb/s signal.

     This fact suggests that the transmitting part for 2.5 Gb/s and the

15 transmitting part for 10 Gb/s can be commonly used for each other. Namely, the transmitting part for 10 Gb/s has just become to be commonly used. Such a transmitting part can be used in an optical communication system for transmission at 2.5 Gb/s, where t_r and t_f are to be quickened.

     According to the above embodiments of the present invention, a signal

20 light is transmitted from transmitting part 1 to receiving part 3 via transmission path 2. Before being transmitted, the t_r and t_f of the signal light are adjusted or optimized, and the signal light may also be provided with pre-chirping, so that the waveform deterioration due to influence of the wavelength dispersion characteristics and nonlinear effect of the transmission path can be effectively

25 reduced and the dynamic range for the signal light to be input to the transmission path is effectively widened. As a result, there can be provided an optical transmission apparatus having excellent transmission characteristics. In addition, the setting of t_r and t_f at transmitting part 1 can be easily done, so that

the optical transmission apparatus can be flexibly matched with various optical communication systems. This results in a reduction of the number of different parts used in an optical communication system, and in lower cost. Moreover, by utilizing the adjustment effect for a waveform by virtue of the optimization of t_r and t_f of the signal light to be transmitted, it becomes possible to commonly use transmitting parts among various optical communication systems, thereby further promoting reduction of the number of parts and of cost.

In some optical communication systems, a dispersion compensator may not be necessary to satisfactorily transmit signal light in accordance with, for example, the system transmission rate, transmission distance, and the number of repeater sections. Therefore, an optical communication system as in FIG. 1 may not require a dispersion compensator. However, in the embodiments of the present invention, a dispersion compensator can be provided to perform dispersion compensation, in addition to pre-chirping and adjustment of t_r and t_f, to thereby avoid waveform deterioration. Of course, a constitution without pre-chirping may be possible. Meanwhile, the present invention is not limited to such a system which is mentioned in relation to the waveform simulation, and can be applicable to any optical communication system. Moreover, although both of t_r and t_f have been adjusted in the above embodiments of the present invention, it is possible to adjust either one of t_r and t_f, without adjusting the other.

FIG. 8 is a diagram illustrating an optical communication system using WDM, according to an embodiment of the present invention. In FIG. 8, those parts identical with the configuration in FIG. 1 are designated by the same numerals.

Referring now to FIG. 8, the optical communication system includes "n" transmitting parts 1_1 to 1_n for outputting respective signal lights of wavelengths λ_1 to λ_n. An optical multiplexer 4 multiplexes signal lights output from

transmitting parts 1_1 to 1_n, to thereby transmit a single wavelength-division multiplexed signal light to a transmission path 2. An optical demultiplexer 5 demultiplexes the wavelength-division multiplexed signal light transmitted via transmission path 2, into respective signal lights of the wavelengths λ_1 to λ_n. "n" receiving parts 3_1 to 3_n receive and process the signal lights from optical demultiplexer 5, respectively. Transmitting parts 1_1 to 1_n are identical to transmitting part 1 in FIG. 1, and receiving parts 3_1 to 3_n are identical to receiving part 3 in FIG. 1.

In FIG. 8, the signal lights are preferably optimized in relation to pre-chirping in a manner identical with that for the embodiment in FIG. 1. Similarly, t_r and t_f at each of transmitting parts 1_1 to 1_n are optimized in a manner identical with that for the embodiment in FIG. 1. The signal lights are then sent to optical multiplexer 4. Optical multiplexer 4 multiplexes the signal lights having wavelengths λ_1 to λ_n transmitted from transmitting parts 1_1 to 1_n, into a wavelength-division multiplexed signal light, and then transmits a wavelength-division multiplexed signal light to transmission path 2. In transmission path 2, the wavelength-division multiplexed signal light is collectively amplified at each of optical amplifiers 22, and finally transmitted to optical demultiplexer 5. During transmission of the wavelength-division multiplexed signal light through transmission path 2, each of the signal lights having the wavelengths λ_1 to λ_n is influenced by, for example, the wavelength dispersion characteristics and/or nonlinear effect of the transmission path. However, each of the signal lights to be transmitted through transmission path 2 has been optimized with respect to pre-chirping and t_r and t_f. Thus, even if the signal lights are influenced by wavelength dispersion characteristics of transmission path 2, the influence is duly offset so that waveform deterioration is reduced.

The wavelength-division multiplexed signal light, which has reached

optical demultiplexer 5, is demultiplexed into signal lights of λ_1 to λ_n, respectively, and thereafter sent to receiving parts 3_1 to 3_n, respectively. Receiving parts 3_1 to 3_n receive the signal lights from optical demultiplexer 5, and duly process them.

5   According to embodiments of the present invention as in FIG. 8, in a WDM optical communication system in which a wavelength-division multiplexed signal light is transmitted, operational characteristics of the system can be improved by optimizing the t_r and t_f of each of the signal lights having wavelengths λ_1 to λ_n, respectively.

10   In the embodiment of the present invention illustrated in FIG. 8, a dispersion compensator is not used. However, the present embodiment is not limited to this configuration, and may include a dispersion compensator to perform dispersion compensation, in addition to pre-chirping and adjustment of t_r and t_f, to thereby reduce waveform deterioration. Of course, a configuration

15 without pre-chirping may be possible. Moreover, although both of t_r and t_f have been adjusted, it is possible to adjust either one of t_r and t_f, without adjusting the other.

         According to the above embodiments of the present invention, a $t_r t_f$ adjusting circuit 13 adjusts the rise time t_r and/or the fall time t_f of a modulation

20 signal.

         FIG. 9 is a diagram illustrating an example of $t_r t_f$ adjusting circuit 13, according to an embodiment of the present invention. Referring now to FIG. 9, a typical configuration for $t_r t_f$ adjusting circuit 13 includes an electrical amplifier 100 to amplify the electrical modulation signal, and a filter 110. Typically,

25 filter 110 would be a low-pass filter. By changing the bandwidth of filter 110, the bandwidth of the series combination of amplifier 100 and filter 110 will change.

         In practice, it is difficult to reduce the rise time t_r and/or the fall time t_f.

Therefore, in a practical system, it may be preferable to actually start with a modulation signal having a faster rise time t_r and/or fall time t_f than finally required. Then, $t_r t_f$ adjusting circuit 13 can be used to increase (length) the rise time t_r and/or the fall time t_f. For example, the configuration in FIG. 9, using a low-pass filter as filter 110, can be used to increase (lengthen) the rise time t_r and the fall time t_f.

In embodiments where the rise time t_r and/or the fall time t_r must be reduced (shortened), filter 110 may not be necessary in $t_r t_f$ adjusting circuit 13.

In some cases, depending on the bit rate of the optical communication system, a simple wire can operate as $t_r t_f$ adjusting circuit 13 to control the rise time t_r and fall time t_f. Typically, this wire would be a microstrip line used at high bandwidths. By changing the wire characteristics, the rise time t_r and fall time t_f can be made longer, or can be kept the same. This approach, using only a wire, generally would be effective with high bit rate (2.5 Gb/s or higher) modulation signals.

Moreover, optical modulator 14 has a corresponding bandwidth. The bandwidth of optical modulator 14 can be changed so that optical modulator 14 operates as a $t_r t_f$ adjusting circuit to change the rise time t_r and the fall time t_f.

There are many different designs which can be implemented as $t_r t_f$ adjusting circuit 13, and, in view of the above, a $t_r t_f$ adjusting circuit would easily be realizable by a person of ordinary skill in the art. The present invention is not intended to be limited to the specific embodiments for a $t_r t_f$ adjusting circuit which are specifically disclosed herein.

According to the above embodiments of the present invention, in a WDM optical communication system, waveform deterioration of signal lights (or "channels") multiplexed together into a WDM signal and having different wavelengths can be reduced by adjusting the rise time and/or fall time of each of the signal lights. Each channel in the WDM signal can have different bit

rates, and $t_r t_f$ adjusting circuit 13 can have the same common configuration for each channel. Similarly, modulation signal generator 12 can have the same common configuration for each channel. This reduces the number of different parts required for the WDM optical communication system, thereby reducing overall system cost. In this case, $t_r t_f$ adjusting circuit 13 (having the same configuration in each channel) and modulation signal generator 12 (having the same configuration in each channel) can be operable at high bit rates (for example, 10 Gb/s), but each channel can be operable at a different bit rate which is equal to, or lower than, this high bit rate. As an example, in FIG. 8, $t_r t_f$ adjusting circuit 13 in each transmitting part 1_1 to 1_n can have the same configuration and be operable, for example, at 10 Gb/s. In this case, for example, each $t_r t_f$ adjusting circuit 13 can have a configuration as illustrated in FIG. 9. At the same time, for example, modulation signal generator 12 in each transmitting part 1_1 to 1_n can have the same configuration and be operable, for example, at 10 Gb/s. Further, each channel can operate at a different bit rate which is equal to, or lower than, 10 Gb/s.

According to the above embodiments of the present invention, a $t_r t_f$ adjusting circuit 13 adjusts the rise time t_r and/or the fall time t_f of a modulation signal. The amount of adjustment of rise time t_r and/or the fall time t_f by $t_r t_f$ adjusting circuit 13 can be set in advance, such as when the system is initially designed or installed. Typically, the amount of adjustment to the rise time t_r and the fall time t_f provided by $t_r t_f$ adjusting circuit 13 is fixed when the system is designed, and is not changed. Therefore, in a typical optical communication system employing the embodiments of the present invention, feedback would not be required to change the amount of adjustment to the rise time t_r and/or the fall time t_f provided by $t_r t_f$ adjusting circuit 13

However, according to embodiments of the present invention, the rise time t_r and/or the fall time t_f can be adjusted based on characteristics of signal

light at a receiver, such as at any of receiving parts 3_1 to 3_n in FIG. 8. As the amount of adjustment performed by $t_r t_f$ adjusting circuit 13 may be very infrequently changed, the characteristics of signal light at the receiver can be visually inspected by a system operator (that is, a human), and appropriate modifications can then be made to $t_r t_f$ adjusting circuit 13 to provide the required adjustment to the rise time t_r and/or the fall time t_f. In some cases, it may be possible to provide automatic control providing feedback so that $t_r t_f$ adjusting circuit 13 is controlled in accordance with reception characteristics.

For example, FIG. 10 is a diagram illustrating a controller 150 controlling $t_r t_f$ adjusting circuit 13 in accordance with characteristics of signal light at receiving part 3. As indicated above, controller 150 can represent human control of visually inspecting the characteristics of signal light at receiving part 3, and making appropriate adjustments to $t_r t_f$ adjusting circuit 13. For example, if $t_r t_f$ adjusting circuit 13 is configured as in FIG. 9 with a filter 110, such adjustments to $t_r t_f$ adjusting circuit 13 might include changing the bandwidth of filter 110.

Moreover, as indicated above, controller 150 can represent automatic control of $t_r t_f$ adjusting circuit 13 in accordance with characteristics of signal light at reception part 2. The design of an electronic controller for detecting reception characteristics at receiving part 3 and automatically controlling $t_r t_f$ adjusting circuit 13 in response thereto, would easily be realizable by a person of skill in the art.

According to the above embodiments of the present invention, an optical transmitting device transmits a signal light modulated in accordance with a transmission signal, to a transmission path. The optical transmitting device transmits the signal light to the transmission path, with at least one of rise time and fall time of the signal light being changed. By changing either one or both of the rise time and fall time of the signal light to be transmitted, it becomes

possible to transmit the signal light having a waveform which can offset an influence of wavelength dispersion characteristics and nonlinear effect of the transmission path. Thus, the waveform deterioration of the signal light after transmission can be reduced. The use of a $t_r t_f$ adjusting circuit allows the rise

5   time and/or fall time of the signal light to be easily modified, so that it becomes possible to flexibly deal with various optical communication systems. This results in reduction of the number of parts or items to be developed, and in lower cost.

Further, according to the above embodiments of the present invention, at

10   least one of the rise time and fall time of the signal light can be adjusted in accordance with reception characteristics of an optical receiving device connected to the optical transmitting device via the transmission path. As a result, there can be provided an optical transmission apparatus and method which is superior in transmission characteristics and has a widened dynamic

15   input range.

Further, according to the above embodiments of the present invention, there may be commonly used another optical transmitting device which is used in another optical transmission apparatus having another transmission rate different from that of the present apparatus. Thus, it becomes possible to use a

20   common optical transmitting device among optical transmission apparatuses having transmission rates different from one another. As a result, it becomes possible to further promote reduction of the number of parts and of cost.

According to the above embodiments of the present invention, signal light is modulated with a modulation signal, such as an electrical modulation

25   signal. The signal light can be modulated by, for example, either optical phase modulation or optical frequency modulation. Thus, there can be conducted pre-chirping onto the signal light to be transmitted from the optical transmitting device to the transmission path, so that the waveform deterioration of the signal

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light after transmission can be further reduced.

Moreover, according to the above embodiments of the present invention, a dispersion compensator can be used to compensate for wavelength dispersion characteristics of the transmission path. Accordingly, the signal light transmitted from an optical transmitting device is passed through the dispersion compensator, so that the wavelength dispersion in the transmission path is compensated, resulting in further reduction of the waveform deterioration of the signal light after transmission. Such a dispersion compensator can be, for example, a dispersion compensation fiber (DCF) positioned along the transmission path. For example, in FIG. 1, one of SMFs 21 can be a DCF.

According to the above embodiments of the present invention, an optical transmitting apparatus includes an adjusting circuit and a modulator. The adjusting circuit adjusts a rise time and a fall time of an electrical modulation signal. The modulator modulates a light with the adjusted electrical modulation signal. Based on a bit rate of the optical communication system and a desired rise time and fall time, the adjusting circuit can (a) shorten the rise time and the fall time, or (b) lengthen the rise time and the fall time. In other embodiments, the adjusting circuit can adjust the rise time and the fall time to maintain amplitude deterioration and phase margin of the modulated light to be within a specific range after being transmitted through a transmission path and received by a receiver .

Although a few preferred embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.